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Abstract

This report documents the continuing efforts to evaluate the operational state of a high pressure PEM based electrolyzer located at the NASA Glenn Research Center. This electrolyzer is a prototype system built by General Electric and refurbished by Hamilton Standard (now named Hamilton Sunstrand). It is capable of producing hydrogen and oxygen at an output pressure of 3000 psi. The electrolyzer has been in storage for a number of years. Evaluation and testing was performed to determine the state of the electrolyzer and provide an estimate of the cost for refurbishment. Pressure testing was performed using nitrogen gas through the oxygen ports to ascertain the status of the internal membranes and seals. It was determined that the integrity of the electrolyzer stack was good as there were no appreciable leaks in the membranes or seals within the stack. In addition to the integrity testing, an itemized list and part cost estimate was produced for the components of the electrolyzer system. An evaluation of the system's present state and an estimate of the cost to bring it back to operational status was also produced.

Electrolyzer Stack Evaluation

This section summarizes the evaluation and testing of the Hamilton Standard high-pressure electrolyzer originally documented in the report titled "Hydrogen Generation through Renewable Energy Sources at the NASA Glenn Research Center" (Ref. 1). This evaluation consisted of a nitrogen pressure test of the electrolyzer stack to determine with greater detail the integrity of the stack membranes. Previous evaluation (described in Ref. 1) of the electrolyzer stack consisted of hydrating the stack by providing a deionized water feed to the stack through the water inlet port. From this initial evaluation it was concluded that the Hamilton Standard electrolyzer stack's membranes were completely hydrated and there appeared to be water leakage from the stack to the pressure chamber that housed the stack. Checkout of the stack over the 4½ months prior to completion of the final report (Ref. 1) in May 2006 led to these conclusions. Since May 2006, there were periodic checks on the water level in the stack over the following 6 months. Table 1 provides volumes of deionized water added at certain times throughout the year through December 2006.

The collected data on the volume of water added to the electrolyzer was surprisingly encouraging with the exception of the last reading. Quantities of water added to the electrolyzer have leveled off and began to decrease somewhat. This can be seen from the last column in Table 1. This perhaps indicates the stack's membranes are hydrated and the loss is due to evaporation, whose rate will be weather related. The last volume of water added to the electrolyzer on December 15, 2006, was submitted just prior to performing the pressure test on the unit. The reason for the added water volume per day increase shown in the last data point is not completely clear. The volume added for this last data point is approximate due to an error in measurement. This approximation of the volume or the lower humidity in December could be the cause of the higher mL/day rate for this last data point.

The purpose of the electrolyzer pressure test with nitrogen gas was to verify the stack condition and or the extent of leakage. The electrolyzer is normally filled with deionized water on the oxygen side of the stack so the pressure test will quantify leak rates to either the hydrogen side of the stack or directly into the pressure chamber. The ability for the stack to maintain pressure or the leak rate will provide a

detailed assessment of the integrity of the seals on the stack. If pressure is maintained this indicates that the seals and cell membranes are intact. Or if a leak is detected this indicates a failure of one or more seals and or membranes within the stack. The rate of leakage (pressure drop) will give an indication of the severity of the failures. However, any rapid pressure drop of the gas represents an internal failure within the stack.

TABLE 1.—VOLUME OF DEIONIZED WATER ADDED
TO THE ELECTROLYZER STACK SINCE MAY 2006

Date	Volume (mL)	mL/Day
June 12, 2006	45	N/A
June 21, 2006	13	1.44
June 29, 2006	10	1.25
July 10, 2006	30	2.72
August 11, 2006	7	0.22
November 11, 2006	113	1.09
December 15, 2006	~100	4.16

Electrolyzer Stack Testing Procedure

The pressure test of the electrolyzer stack was performed on December 15, 2006, using high purity nitrogen gas over a range of pressures to provide a top level indication as to the stack's condition. For the testing, the nitrogen gas pressure was increased up to a level just below 30 psig. A relief valve, set at 30 psig, was used to ensure that this maximum pressure level was not exceeded. Figure 1 captures the individual tests performed on the stack. The first step was to remove the deionized water from the stack by opening all gas ports (nitrogen, oxygen, hydrogen) and then supplying nitrogen gas at 5 psig into the distilled water feed line. This pressurized gas forced the majority of the deionized water out of the stack. Each of the gas ports have been identified in the schematic (Fig. 1) along with the appropriate SSP fitting used to perform the outlined tasks.

After removing the contained deionized water from the stack, the next step was to pressurize the oxygen side of the stack with nitrogen to see if the gas passed onto the hydrogen side, which would indicate a leak in either a seal or membrane. The nitrogen pressure was adjusted in 5 psig intervals up to a supply pressure of 29 psig. At 25 psig, the cap was removed off the nitrogen port (8) to simultaneously check for leaks into the pressure chamber. After performing the oxygen side pressure testing, it was decided to confirm the electrolyzer's normal mode of operation of being fed distilled water on the oxygen side of the stack. This was accomplished by capping the hydrogen port (6), opening the oxygen port (1), and applying 5 psig of nitrogen to the system through the water inlet port. The valve directly on the nitrogen k-bottle was closed and the pressure was seen to drop immediately in the supply line confirming water feed to the oxygen side.

The final step in the test procedure was to pressurize the oxygen side with nitrogen to see if leaks occurred directly into the chamber. The nitrogen pressure was adjusted in the same manner as performed earlier (5 psig intervals up to 29 psig).

After performing this final checkout test, the nitrogen test assembly was removed and all liquid/gas ports were capped except for ports 1 and 6 located on the pressure chamber. This was done to allow for evaporation of trace amounts of water from the stack pressure chamber prior to storage. These ports were left open for 1 week and then capped on December 22, 2006, to keep the pressure chamber free of contaminants.

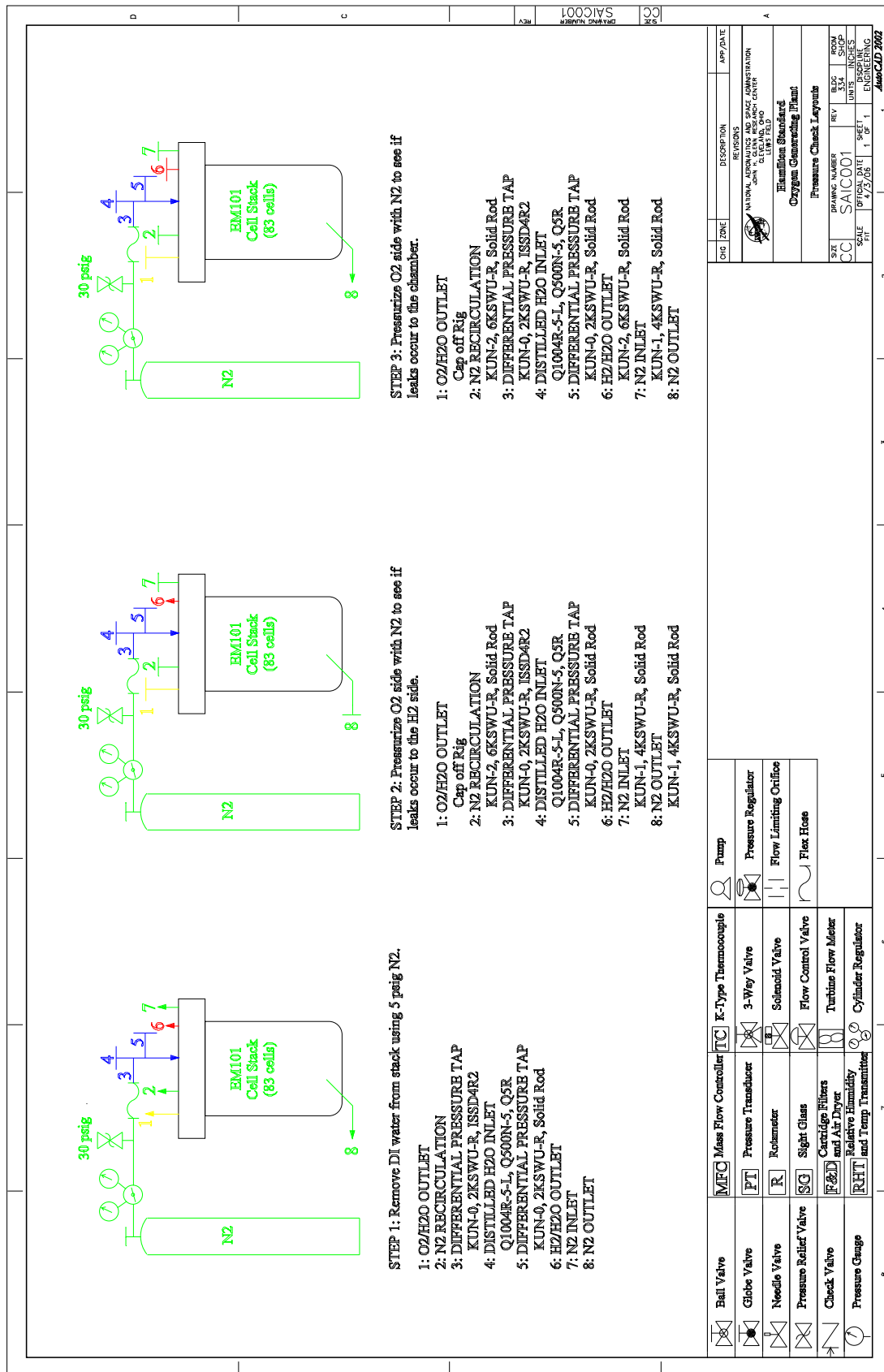


Figure 1.—Individual electrolyzer stack checkout steps.

Electrolyzer Stack Test Results and Conclusions

During the water removal procedure (Step 1), most of the water was seen to blow out of the oxygen port at 5 psig. A small amount was seen to remain behind as it fell back by gravity down the oxygen port into the stack. Due to the pressurized nitrogen gas flow, the water within the stack abruptly shot into the air and was not able to be captured for measurement.

The first nitrogen leak test from the oxygen to the hydrogen side of the stack resulted in no observed pressure drop at supply pressures of 5, 10, 15 and 20 psig. The nitrogen pressure held at each interval for approximately 2 min. At 25 psig, nitrogen port 8 at the bottom of the vessel was opened and the pressure was seen to hold steady for about 5 min confirming no major leaks to either the hydrogen side of the stack or into the chamber. Port 8 was kept open and the pressure was increased to 29 psig. After 10 min had elapsed, the pressure was seen to drop to only 28 psig. Overall, after a total of 20 min of elapsed time, the pressure dropped to only 27 psig.

The second leak test from the oxygen side of the stack to the pressure chamber similarly resulted in no observed pressure drop at supply pressures of 5, 10, 15, 20 and 25 psig. The nitrogen pressure was held at each interval for roughly 2 min except at 25 psig where the stack held at pressure for about 4 min. The pressure was then increased to 29 psig and after 10 min had elapsed, the pressure was seen to drop to only 28.5 psig. The stack remained at 28.5 psig for another 5 min before the checkout was terminated.

Both tests indicate that there is no major defect with the stack. The observed 2 psig drop during the first test was due to the membrane's permeability and perhaps very minute leaks at the electrolyzer's fittings. The water level in hydrogen port 6 rose slightly during the first test confirming the membrane's permeability.

A torn membrane or a ruptured/cracked seal would have resulted in a very rapid drop in pressure, even at low supply pressures such as 5 psig. Since this type of event did not occur during the oxygen side to hydrogen side pressure testing, it can be concluded with a high degree of certainty that the high pressure electrolyzer stack is in good condition and free from any appreciable leaks due to membrane or seal failure.

Evaluation of the State of the Electrolyzer System

The purpose of this evaluation is to identify the components and/or systems (other than the actual stack) that will need to be refurbished or replaced. A visual inspection was performed on the electrolyzer system, noting most of the significant components that make up the balance of plant. Overall the state of the electrolyzer system components was fairly poor. The majority of the system will need to be replaced and due to the age of the system and the compatibility of the components installed with commercially available newer components, it may be more cost beneficial to completely rebuild the fluid and control systems than to try and salvage any of the components.

There are a number of open lines and severed electrical connections that would need to be completely replaced. The open lines are of particular concern since the cleanliness of the system is critical to the operation of the electrolyzer stack and with the use of oxygen in the process lines. Figures 2 through 7 provide examples of the present state of the system components.

The above figures show an example of the state of the system's mechanical and electrical components. Although some components may be salvageable, it is recommended that the system be completely rebuilt utilizing the electrolyzer stack and containment vessel. The containment vessel was sealed off from the fluid lines and therefore should be contaminant free and based on the results of the pressure testing the stack should be in good operational condition. Table 2 gives a summary of the estimated replacement cost for most of the major system components.



Figure 2.—System cabinet.



Figure 3.—Electrolyzer system cabinet base.



Figure 4.—Cut power and data cable interfaces.

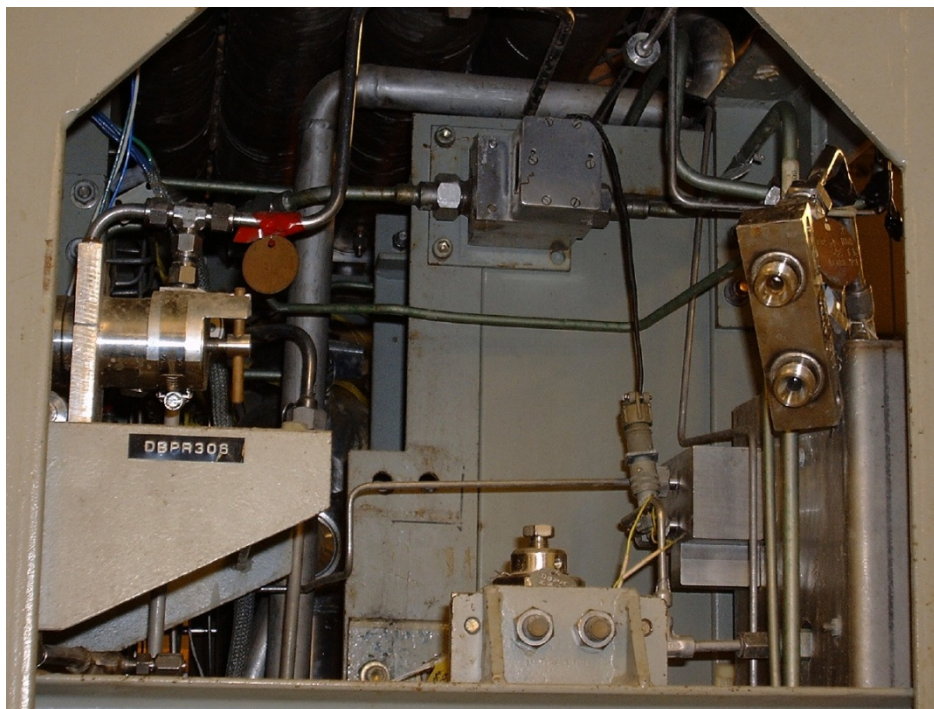


Figure 5.—Disconnected internal components.



Figure 6.—Electrolyzer stack pressure vessel with disconnected fluid lines.

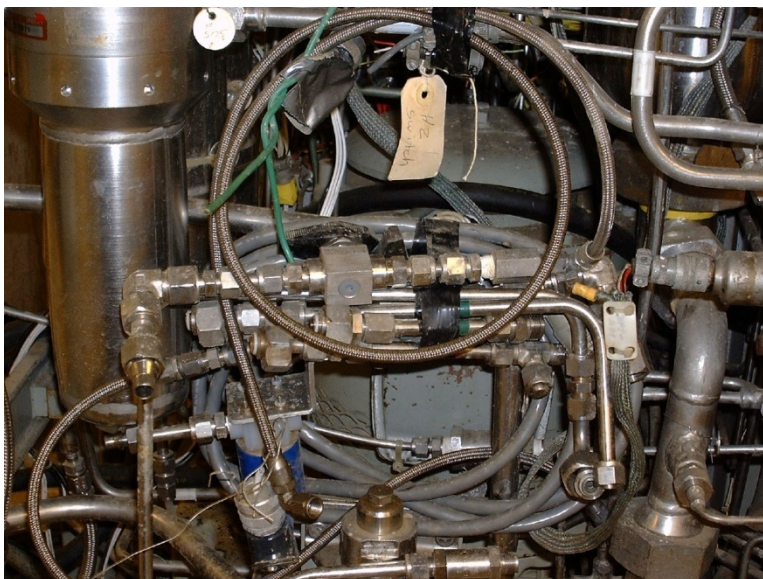


Figure 7.—Disconnected internal fluid lines.

TABLE 2.—ELECTROLYZER SYSTEM COMPONENT COST SUMMARY

Component type	Manufacturer	Part number	Quantity	Total estimate replacement cost
Normally Closed Actuated Valve	Nupro	SS-HBS6-C	5	\$1,616
Normally Open Actuated Valve	Nupro	SS-HBS6-O	3	\$970
Back Pressure Regulator	Not Available	Not Available	2	\$1,600
Circulation Pump	Midland Ross	970P100	1	\$1,100
Check Valve	Not Available	Not Available	10	\$650
Differential Back Pressure Regulator	General Electric	Not Available	1	\$800
Differential Back Pressure Regulator	Tescom	269-403	2	\$1,600
Differential Back Pressure Regulator	Tescom	269-454-2	1	\$800
Differential Back Pressure Regulator	Tescom	269-402	1	\$800
Differential Pressure Regulator	General Electric	Not Available	2	\$1,600
Differential Pressure Transducer	Shaevitz	P2194-001	3	\$2,250
	Viatran	220-15	1	\$750
Electronic Control Valve	Hewlett Packard	Not Available	3	\$3,315
Filter	Not Available	Not Available	6	\$300
Rotameter	Fischer & Porter	10A3135	3	\$450
Feed Pump	March Mfg. Co.	TE-7R-MD	1	\$1,200
Gas Analyzer	Control Inst.	B7SNR006	3	\$6,000
Heat Exchanger	Not Available	Not Available	1	\$750
Hydrogen Phase Separator	Not Available	Not Available	2	\$7,000
Heater	Not Available	Not Available	1	\$900
Level Switch	IMO Delaval	Not Available	3	\$590
Oxygen Phase Separator	Not Available	Not Available	1	\$8,000
Orifice	Not Available	Not Available	8	\$160
Pressure Gauge	Not Available	Not Available	7	\$420
Pressure Regulator	Not Available	Not Available	3	\$2,400
Pressure Switch	Kratos	50820	1	\$75
Pressure Transducer	Shaevitz	P793-001	5	\$3,750
Resistivity Sensor	Foxboro	CEL-272	3	\$1,275
Temperature Sensor	RdF	21SP-A-10	4	\$360
Relief Valve	Circle Seal	P13-485	7	\$840
Solenoid Valve	Asco	Not Available	15	\$1,800
Manual Valve	Circle Seal, Hoke	Not Available	21	\$4,850
Venturi	Not Available	Not Available	1	\$125
Resistivity Monitor	Foxboro	874RS-AT	1	\$300
DH-485 PC Interface	Allen Bradley	1747-KE	1	\$600
TOTAL				\$45460

The electrolyzer system can be refurbished in house at NASA Glenn or returned to the manufacturer for complete refurbishment. The majority of the cost for rebuilding the electrolyzer in-house will be in technician and engineering time. Without being able to evaluate the electrolyzer stack in detail, the manufacturer cannot provide a detailed cost estimate for its refurbishment. However, based on previous system work an estimate of the refurbishment cost and or labor hours can be made. These are given in Table 3.

TABLE 3.—ELECTROLYZER SYSTEM REFURBISHMENT COST ESTIMATE

	Estimated manufacturer refurbishment	In-house refurbishment
Estimated cost or labor hours	\$435,000 labor \$ 65,000 parts	320 engineering hours 400 technician hours plus hardware costs

Should a program arise to use the electrolyzer system, the recommendation would be to have Hamilton Standard aka Hamilton Sundstrand refurbish the system. Hamilton Sundstrand would come on-site to perform a complete, detailed analysis of the stack's integrity and quote an actual refurbishment cost based on their observations and findings. Their prior working knowledge of the overall system is invaluable and the refurbishment cost will most likely be lower than having the work performed in-house.

References

1. Colozza, A.J. and Prokopius, K., "Hydrogen Generation through Renewable Energy Sources at the NASA Glenn Research Center", NASA/CR 2007-214682, April 2007.

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